ACE Instrument Concepts: Additional Requirements for Clouds*

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1. Wide vs. Narrow Swath Rationale
2. Wide Swath Infrared Imagery - providing present-day EOS/A-Train cloud capabilities
3. Wide Swath Microwave/Sub-millimeter Imagery

** Further details in ACE Cloud White Paper, Winter 2010*

A Look at Decadal Survey's ACE Text (part of "Climate Mission 1")

Chapter 9: CLIMATE VARIABILITY AND CHANGE

- DS Climate Panel had the vision of a full A-Train complement for Cloud-Aerosol studies.

  p. 270: "The mission could fly in formation with the 1:30 NPOESS satellite (C-1) … Combined with the NPOESS instruments, the instrument package of CM1 would **mimic the relevant capabilities of the A-Train** (Aqua MODIS, Aura OMI, CloudSat, CALIPSO, POLDER, and Glory) while substantially advancing the technology …"

- DS panel never intended to have a cloud mission w/out a full complement of IR and VNIR capabilities.

  p. 273: "… the ideal configuration would be to fly CM1 at the same orbit altitude as the NPOESS spacecraft (about 820 km) … to take advantage of the VIIRS … One technical difficulty with this payload is that an 820-km orbit is a challenge [for active sensors]. **A lower orbit would be feasible if the VIIRS visible and IR bands could be included in the polarimeter**."

A Look at Decadal Survey's Text in "Aerosol-Cloud Discovery Mission (A-CD)"

Chapter 10: WEATHER SCIENCE AND APPLICATIONS

- DS Weather Panel also articulated the need for a cloud-aerosol mission, emphasizing a hydrological focus.

  p. 320: "… Some mission concepts were regarded as having high priority by several panels, including the weather panel. **This panel's top priority is a science mission to understand the linkages among clouds, aerosols, and Earth's hydrologic cycle**."

- Weather panel recognized the need for submillimeter and IR observations in addition to ACE-like sensors.

  p. 320: "Sensors: Multiwavelength aerosol lidar, Doppler radar, spectral polarimeter, A-band radiometer, **submillimeter instrument, IR array**. **…** the primary instrument measures at submillimeter wavelengths (183-874 GHz) for ice path"

Wide + Narrow Swath Imagery for Clouds (1)

"Two-swath" approach:

- Narrow Swath
  - Consisting of nadir pointing active sensors and polarimeter w/high-resolution imagery (~100 m) in selected spectral channels along a narrow swath of order ~100 km.
  - High resolution => resolve spatial scales smaller than those of radar footprint or effective lidar averaging length to assess inhomogeneities.
- Wide Swath
  - Lower spatial resolution observations from a variety of passive systems (polarimeter, IR, submm/μwave) over a ~1500 km wide swath; ~500 m to 1 km spatial resolution in solar/IR, ~10 km in submm.
  - Also provides full spectral/polarimetric capability for synergistic active cloud retrievals along the nadir curtain.

Wide + Narrow Swath Imagery for Clouds (2)

Wide swath IR/sub-mm rationale:

- Cloud-Aerosol synergy: Complement polarimeter/imager swath for aerosols. Off-curtain aerosol retrievals ought to be accompanied by best cloud retrievals possible for process and correlative studies.
- Process-oriented case studies and events of interest. Allow for the supporting such studies, and enabling science on transient large-scale geophysical events/phenomena.
- Context for Curtain Measurements: Passive observations across a range of horizontal scales can capture the larger cloud, aerosol, and meteorological context for which the specialized curtain retrievals are obtained.
- Pathway to Model Improvement: Retrievals on wide swath scales enable cloud assimilation which we envision as a pathway to model improvement (assimilation analysis provides meaningful insight into physical processes and model diagnostics).

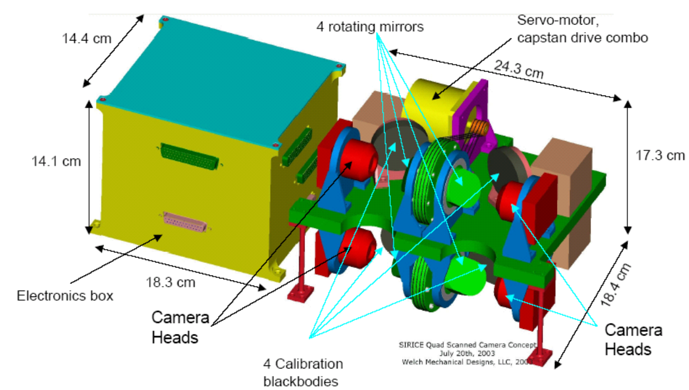
Infrared Imagery (1)

Can’t comprehensively assess clouds without a minimal IR capability.

- 4+ decades of experience in using IR for:
  - cloud detection, high cloud property retrievals (emissivity, radiative temperature/pressure, cirrus optical properties), phase, LW radiation budget studies, water cloud particle size (3.7 μm), and synergy with solar reflectance imagers and other instruments.
- IR-derived cloud data sets include:
  - ISCCP (IR window), HIRS (sounding channels), AVHRR PATMOSx (2 IR window channels), MODIS (3.7, 8.5 μm, window (2), 13-14μm CO_2 channels), AIRS (3.7-15 μm), CALIPSO/IIR (8.5, 11, 12 μm). Future: NPP/JPSS (VIIRS, CrIS).
- Information content is complementary to solar reflectance/ polarization and active sensors (not equivalent), as well as submm/μwave ice and liquid water path capabilities.

Infrared Imagery (2)

- Needs
  - Requirements: 3.7, 8.5, 11, 12 µm spectral channels; ~1km spatial resolution. Represents a bare-bones and limited capability compared with current/future IR imagers.
  - Goal: CO_2 channels (13-15 µm, MODIS-like)
- Instrument studies (w/out 3.7 µm band): SIRICE Infrared Cloud Ice Radiometer (IRCIR), IDL concept study, 2004; U. Wisconsin/ SSEC study: ~2005



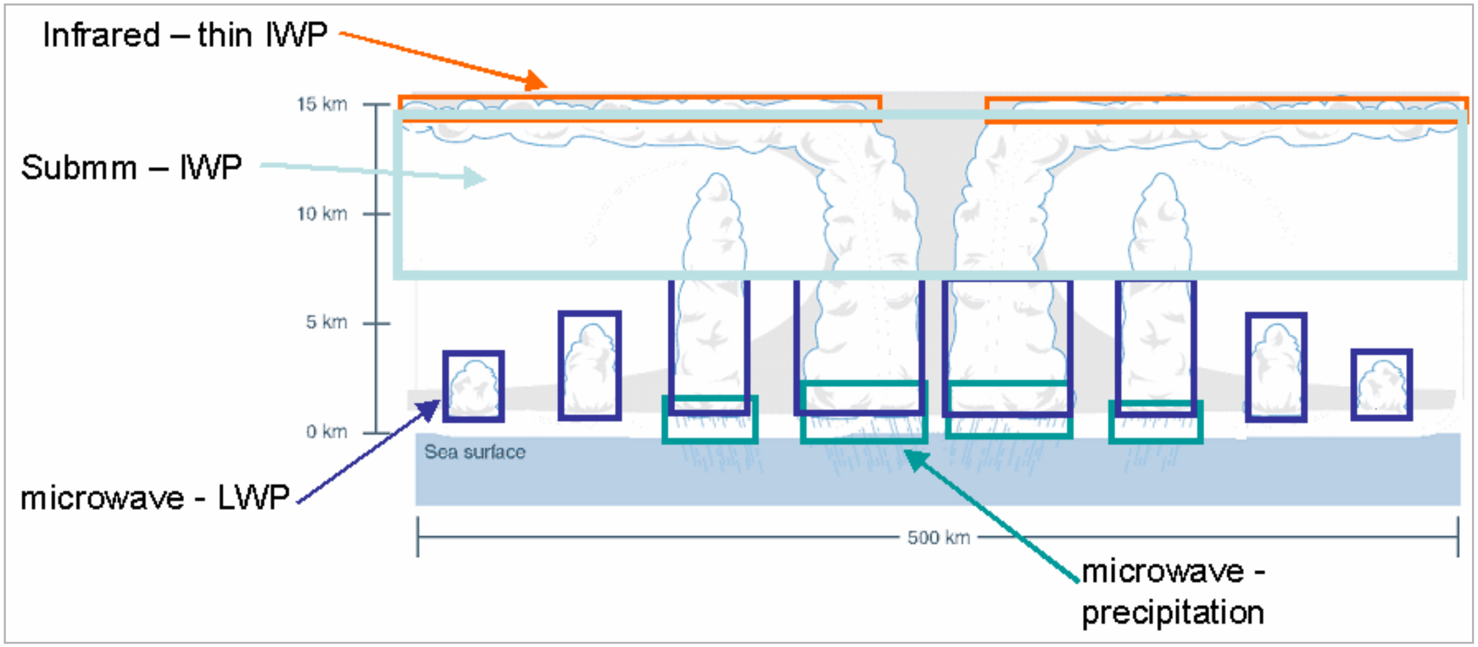
  - Pushbroom, ~1500 km swath
  - Uncooled microbolometer FPA
  - Lightweight (~10 kg), low power (~30W)
  - Multiple cameras/view options (TBD)
  - Inexpensive (~$30M)
  - Heritage: Infrared Spectral Imaging Radiometer (ISIR) flown on STS-85 (1997), developed under SBIR; Compact Infrared and Visible Imagers (CoVIR), IIP-98 task.

Submm/μwave Imagery (1)

- Submillimeter/millimeter retrieval capabilities:
  – Provide accuracies of ~25% cloud ice water path (IWP) and median mass equivalent particle size (Dme).
  – Submm will improve radar-derived IWC(z) accuracy by providing overall IWP constraint on the profile retrieval.
  – Greater dynamic range of ice mass when submm flown with IR. Combined submm + IR Bayesian algorithms have been developed/ published (F. Evans).
- Microwave imager capabilities:
  – Provides LWP (complement to submm IWP), precipitation estimates, SST, column water vapor, ocean surface winds

Submm/μwave Imagery (2)

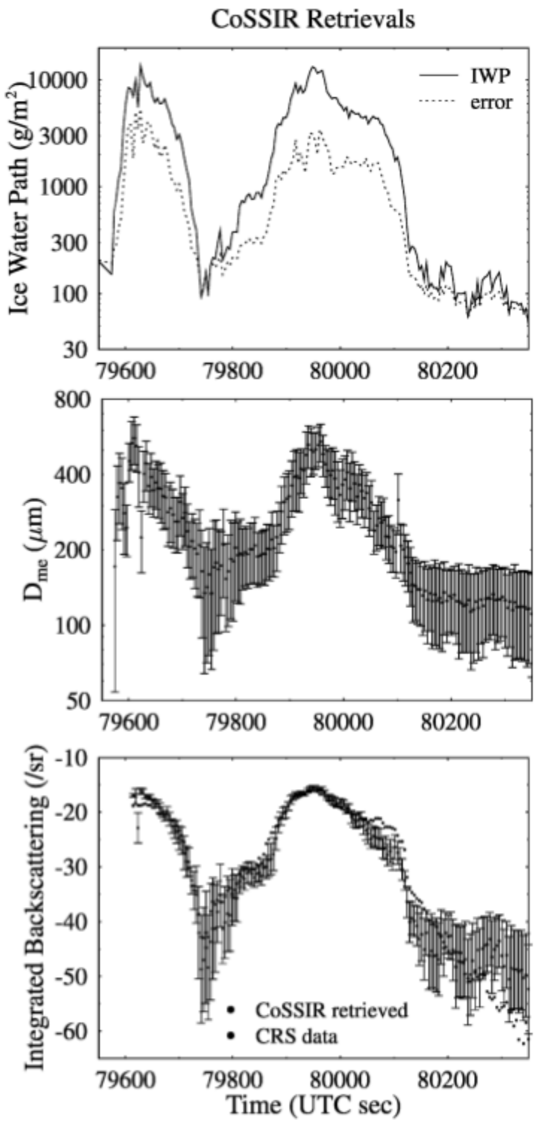
IR/Submm/μwave synergy



At sub-mm frequencies:

- lower atmosphere opaque due to strong H_2O absorption, upwelling vapor emission scattered by ice particles w/brightness temperature depressions proportional to the IWP
- sub-mm frequencies sensitive to the particles containing most of the ice water mass; different frequencies can be used to quantify an effective mass-weighted size.

Submm/µwave Imagery (3)



Example CoSSIR retrievals from CRYSTAL-FACE

top, middle figures: IWP and median mass diameter retrievals (with error bars), respectively.

bottom figure: Vertically-integrated radar reflectivity compared to forward model from CoSSIR retrievals.

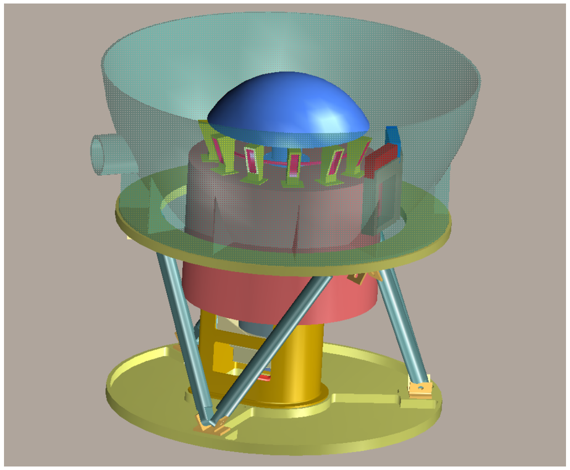
[Evans et al., *J. Appl. Meteo.*, 2005].

Submm/μwave Imagery (4)

- Submm instrument concept: SM4 (SIRICE IDL study, 2004)
  - Conical scanning,10 km spatial resolution,~1500km swath
  - 12 channels/6 receivers (183 - 874 GHz)
  - 134 kg, 182 W, 211 kbps, ~$75M (approx. FY11 $'s)
- Submm heritage
  - MLS on Aura (limb scanning); CoSSIR aircraft instrument.
  - ESTO investment: IIP-08, ACT-05 (2 tasks)

Sideband Channels (GHz)

- 183.31 ±1.5, ±3.5, ±7.0
- 325.25 ±1.5,±3.5, ±9.5
- 448 ±1.4, ±3.0, ±7.2
- 640 ±6.7 H
- 640 ±6.7 V
- 874.4 ±6.7



ACE Instrument Concepts: Additional Needs for Clouds – Summary

1. **Legacy synergy**
   - Infrared Imager:
     - recognized explicitly in DS Climate Panel text
     - low cost uncooled bolometer FPA approach (IRCIR) covers part of the spectral requirements
   - VNIR/SWIR spectral/spatial capabilities for cloud studies
     - very close to polarimeter requirements, close for OES
2. **Additional synergy with microwave/sub-millimeter imagery**
   - Recognized explicitly in Weather/App. Panel text
   - IDL sub-mm study completed in 2004
3. **A-Train legacy and formation flying**
   - *Recommendation*: programmatic-level discussion w/international partners and other DS/Climate missions on formation flying in support of clouds-aerosols-hydrology science [*see "extra" slide for missions of interest*] and/or other DS science.

Extras

Some ACE-related Missions of Interest

Solar reflectance imagery/polarimetry:

- Mission for Climate and Atmospheric Pollution (MCAP): polarimeter, CSA APOCC (Atmospheric Processes Of Climate and its Change) program, J. Drummond

Precipitation:

- SnowSat (35/94-GHz Doppler cloud radar): CSA APOCC, P. Joe
- AMSR2/GCOM-W2, -W3: JAXA

Other:

- EarthCare operations precede current ACE launch window: 2014, ~400 km, no wide-swath sensors (MSI: 150km swath, 500m, 7 channels: 0.67, 0.86, 1.65, 2.21, 8.8, 10.8, 12 μm)
- JPSS: as with NPP, flies at 825 km orbit. No plans for formation flying.

Note: APOCC missions under study (no down-select yet) but would nominally launch before 2020.

VNIR/SWIR Needs for Clouds

- Ocean Ecology Sensor (OES) will be very useful for clouds; ocean team has been very helpful in reaching out to cloud team.
- However, OES doesn't meet spatial resolution and some spectral requirements. Cloud group minimum requirements beyond OES requirements:
  - <u>Spectral</u>: missing water vapor at 1.38/1.88 μm (for cirrus detection, ice cloud properties). Potentially a 2nd 1.6 μm (or 2.2 μm) window channel to assist in cloud phase discrimination. With O_2 A-Band capability, of less importance is 0.94 μm requirement (column water vapor, multilayer detection).
  - <u>Spatial</u>: OES 1km resolution vs. 500 m (and ~100 m for selected narrow swath channels).
  - <u>Pointing</u>: Some latitudinal gaps due to off glint pointing, but imager expected to stagger the tilt N&S such that there are no gaps in weekly averaged binned data
- Cloud group Minimum Requirements (MR) are very close to Polarimeter requirements. Additional discussions needed regarding:
  - Swath coverage w/complete multiangle/polarimetry observations.
  - Some concerns about spectral coverage and spatial resolution.